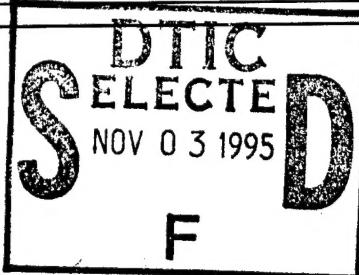




Mississippi State UNIVERSITY

Center for Air Sea Technology



A UNIFIED AIR-SEA VISUALIZATION SYSTEM: SURVEY ON GRIDDING STRUCTURES

by

Harsh Anand and Robert Moorhead

Technical Report 95-03

30 September 1995

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Mississippi State University Center for Air Sea Technology
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TECHNICAL REPORT 95-3

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SURVEY ON GRIDDING STRUCTURES**

by

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30 September 1995

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ABSTRACT

The goal of this project is to develop techniques and a visualization system to enable the rapid fusion of observational, archival, and model data for verification, analysis, and integration of that data, especially from the model. To design and develop such a Unified Air-Sea Visualization System (UASVS), scientists associated with major ocean and atmosphere modeling systems were polled to determine: (1) the gridding structures predominantly used, (2) the visualization systems presently used, and (3) their needs with respect to visual analysis. This information will be used to determine the direction of the UASVS development and to develop optimum strategies for approximating onto (hierarchical) spherical curvilinear grids. A basic UASVS requirement is to allow a modeler to explore (view) multiple (measured or computed) data sets within a single environment, or to interpolate multiple datasets onto one unified grid and visualize the reduced data.

The main results from this survey are that the UASVS should be able to visualize 3D scalar/vector fields; render isosurfaces; visualize arbitrary slices of the 3D data, as well as horizontal, vertical, and isopycnal surfaces; visualize data defined on spectral element grids with the minimum number of interpolation stages; render contours; produce 3D vector plots and streamlines; provide unified visualization of satellite images, observations and model output overlays; display the visualization on a sphere or a map projection of the users' choice; implement calculator functions so that the user can derive various diagnostic values; animate the data to see the time-evolution of the model output; animate ocean and atmosphere at different rates; store the record of cursor movement as the user follows a feature of interest, smooths the path, and automates the animation of a window around the moving path; repeatedly start and stop the visual time-stepping at any time during the animation; generate good quality VHS tape animations; work on a variety of workstations; and allow visualization to be distributed across clusters of workstations and/or scalable high performance computer systems.

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1. INTRODUCTION

The specific goal of this project is to develop techniques and a visualization system to enable the rapid fusion of observational, archival, and model data for verification, analysis, and integration of that data, especially from the model. The approach involves four steps. First, the principal existing air and sea gridding structures will be determined. Second, a spherical curvilinear gridding system will be developed. Routines will be generated to produce hierarchical, spherical, curvilinear grids with local geometrically-driven refinement. Third, data interpolation and approximation techniques will be developed for mapping data from multiple models, measurements, and archival sources onto the spherical grid. Routines to approximate and interpolate scattered data, data on unstructured (triangular) grids, and data on structured grids will be generated. Finally, scalar and vector field visualization paradigms will be developed for environmental data stored on a hierarchical spherical curvilinear grid. This visualization system will allow the display of environmental, tactical, and contextual data. Functionality to animate scenes, to extract slices, and to compute derived data will be included.

The mapping and visualization routines will be prepared and tested in collaboration with various ocean and atmospheric modelers to assure their utility, validity, and functionality.

The long term goal is to create a uniform reference gridding environment for environmental data in spherical coordinates. The purpose is to allow one to map and visualize environmental and related data (objects and symbols) simultaneously, in a graphical depiction that gives the same perspective as the real spherical earth-atmosphere. Thus, the goal is provide an easily interpreted graphical depiction that directly relates to what a user relates to in the real physical world. The difficult part is to do this in a way that is both efficient and accurately represents the data, and yet is easy to use.

To design and develop a Unified Air-Sea Visualization System (UASVS), as described above, scientists associated with major ocean and atmosphere modeling systems were polled to determine: 1) the gridding structures predominantly used, 2) the visualization systems presently used, and 3) their needs with respect to visual analysis. This information will be used to determine the direction of the UASVS development and to develop optimum strategies for approximating onto (hierarchical) spherical curvilinear grids. A basic UASVS requirement is to allow a modeler to explore (view) multiple (measured or computed) data sets within a single environment, or to interpolate multiple datasets onto one unified grid and visualize the reduced data.

The intent of this survey was to gain information on the:

- (a) Nature of the three-dimensional (3-D) grid structures employed by different ocean and atmosphere models so that they can be incorporated as UASVS options and to develop the optimal interpolation algorithms;
- (b) Spatial distribution of variables on 3-D computational grids, such as Arakawa A/B/C, so that appropriate spatial locations can be assigned to various fields while mapping them onto the UASVS grid;
- (c) Metadata, in particular the size of the data sets, the various data formats, the data access methods, and the land/water masking information that UASVS will be expected to handle;
- (d) Various climatological data sets that should be accessible by UASVS;
- (e) Current computing environment weaknesses and strengths;
- (f) Scientists' recommendations for the desired features for the visualization system; and
- (g) Foreseeable challenges and possible solutions.

The survey questions are provided in Appendix A, and the list of scientists surveyed is included in Appendix B.

2. PRINCIPAL (EXISTING) GRIDDING STRUCTURES

2.1 Ocean Models

The 3-D computational grid for an ocean domain is usually cast as a composition of a 2-D grid in the horizontal with a 1-D partition of the vertical space into levels or layers. The horizontal gridding and the vertical partitioning are usually performed as separate and distinct operations. The 2-D horizontal grids, specified as longitude and latitude points, are usually either rectilinear or curvilinear orthogonal. The principal gridding structures can be classified as follows:

Horizontal Structures

- A regular grid characterized by constant grid spacings along the two coordinate axes. It is specified by providing the origin, $(X(1), Y(1))$, the increments (DX, DY), and the maximum number of intervals ($IMAX, JMAX$) in the two directions. The grid is formed by points $(X(I), Y(J))$, where $X(I) = X(1) + (I - 1) * DX$ and $Y(J) = Y(1) + (J - 1) * DY$.

- A rectilinear grid is characterized by variable grid spacings along the two coordinate axes. It is specified by providing $X(1) < X(2) < \dots < X(IMAX)$ and $Y(1) < Y(2) < \dots < Y(JMAX)$. Then the grid points are given by $((X(I), Y(J))), I = 1, 2, \dots, IMAX; J = 1, 2, \dots, JMAX$.
- A curvilinear orthogonal grid is characterized by irregular positions specified explicitly in terms of two two-dimensional arrays $X(I, J)$ and $Y(I, J)$. In this case, the grid points are obtained as $((X(I, J), Y(I, J))), I = 1, 2, \dots, IMAX; J = 1, 2, \dots, JMAX$.
- An unstructured grid is characterized by scattered positions specified explicitly in terms of a list of points and their connectivity, which is usually via triangles. Note, however, that the Spectral Finite Element Model (SFEM) uses unstructured quadrilaterals, in which the cells are quadrilaterals, but the connectivity at each node is not necessarily four.

Vertical Structures

- Z-levels, for which the depth levels are horizontal planes, although the spacing between the planes may be variable;
- Sigma coordinates, in which each level is at a fixed percentage of the water column at each sample point, i.e., sigma coordinates are bottom conforming.
- Hybrid z-levels, which are a combination of sigma coordinates for the lower part and flat z-levels for the near-surface part of the ocean;
- Semi-spectral modes, for which the layers are specified in terms of vertical basis functions (sigma layout) or Chebychev polynomials (collocation method);
- Isopycnal (equal density) layers;
- Structured quadrilateral elements which conform to the bottom topography.

The gridding structures of the major numerical ocean models are summarized in Table 1.

Table 1. Grids for Major Numerical Ocean Models

Model	Grid Type	Horizontal	Vertical
Princeton Ocean	Structured	Curv. orth.	Sigma levels
ECOM-SIZ*	Structured	Curv. orth.	Z-levels
Harvard Ocean	Structured	Curv. orth./ Rectangular/ Rectilinear	Hybrid system/ Sigma levels
CAST DieCAST*	Structured	Rectilinear	Z-level
NRL Layered	Structured	Rectilinear	Layered
Florida State	Structured	Rectilinear	Layered
Rutgers SPEM*	Structured	Curv. orth.	Semi-spectral modes
Rutgers SFEM	Unstructured	Unstructured quads.	Structured elements bottom conforming

* ECOM-SIZ—*Estuarine and Coastal Ocean Model (Semi-implicit Z-Level)*; SPEM—*Semi-Spectral Primitive Equation Model*; CAST DieCAST – *Center for Air Sea Technology Dietrich CAST Model*

2.2 Atmospheric Models

The 3-D grids for atmospheric models are very similar to the ocean model grids described in section 2.1. They are also usually cast as a composition of a 2-D grid in the horizontal with a 1-D partition of the vertical space into levels or layers. The 2-D horizontal grids, specified as (longitude, latitude) points or in a map projection coordinate system, are either rectilinear or unstructured grids. The map projection coordinate system refers to the relationship between the rows and columns of data in the 3-D grid and the latitude/longitude of the earth. The vertical decomposition is one of:

- Z-levels;
- Terrain-following sigma levels;
- Hybrid z-levels which are a combination of sigma coordinates for the lower part of the atmosphere and the pressure coordinate for the upper part of the atmosphere;
- Isobar Levels (constant pressure).

Since our goal is to provide a unified visualization system for Navy use, the development will emphasize the Navy's operational nowcast/forecast atmospheric spectral models: the coarse resolution Navy Operational Global Atmospheric Prediction System (NOGAPS) and the fine resolution nested grid Navy Operational Regional Atmospheric Prediction System (NORAPS). Both models are routinely run at the Fleet Numerical Meteorology and Oceanography Center (FNMOC). Other models being used at the Naval Postgraduate School (NPS) are the National Meteorological Center (NMC) models and the Fifth Generation Pennsylvania State University (PSU)/ NCAR Mesoscale Modeling System (MM5), both of which use a Lambert conformal projection. The gridding structures of the major atmospheric models are given in Table 2.

Table 2. Grids for Numerical Atmospheric Models

Model	Grid Type	Horizontal	Vertical
NCAR MM5	Structured	Rectilinear	Sigma Levels
NMC	Structured	Rectilinear	Pressure Levels
NOGAPS	Structured	Rectilinear	Hybrid System
NORAPS	Structured	Rectilinear	Hybrid System

3. COMPUTATIONAL GRIDS

For mapping of the various fields to the unified grid, it is important to know the exact lattice of the grid to be mapped. Various techniques used in atmosphere and ocean modeling of fluid dynamics are: finite differencing, spectral methods, and finite element methods. In the ocean modeling systems mentioned above, finite-difference schemes are employed by all but the Rutgers group, who use a combination of finite-difference and spectral methods and 3D spectral element methods. Some models employ a staggered arrangement of horizontal grid points in which temperature/pressure points can be thought to be at the centers of gridboxes and u and v velocity components reside together at the centers of the vertical edges of the gridboxes (the so-called Arakawa B scheme). This method allows a relatively straightforward advection calculation and a semi-implicit treatment of the Coriolis term, without which the time-step is severely limited in coarse-grid models. However, the placement of u points at the

centers of the meridional faces of gridboxes and of v points at the centers of latitudinal faces (the so-called Arakawa C scheme) is even simpler (less averaging) and might be selected if resolution is fine enough not to require semi-implicit treatment of Coriolis terms. Still other models use a blend of Arakawa A and Arakawa C grids, in order to take advantage of strong features of each grid, by interpolating between the grids as needed. The choice of scheme depends on grid resolution; most coarse grid model studies have used the B scheme and most eddy resolving studies have used the C scheme. Winninghoff (1968) found that the simulation of the geostrophic adjustment process with a finite-difference scheme is highly dependent on the manner in which variables are distributed over the grid points. However, the gridding schemes like the Arakawa grids are not applicable for the spectral models as all the variables are computed from the spectral coefficients at a collocated point. See Table 3 for a summary of the computational grids used in various numerical ocean models.

Table 3. Computational Grids Used in Major Numerical Ocean Models

Model	Variables distribution
Princeton Ocean	Arakawa C
ECOM-SIZ	Arakawa C
Harvard Ocean	Arakawa B
CAST DieCAST	blend of Arakawa A and Arakawa C
NRL Layered	Arakawa C
Florida State	Arakawa C
Rutgers SPEM	Arakawa C
Rutgers SFEM	surface height staggered w.r.t. velocity; Arakawa A/C n.a.

4. METADATA

The sizes of data sets that will be analyzed with UASVS are directly proportional to the resolutions of the models. With the enhancements in computational speed and memory capacity, and with the operational requirements of the Navy, the number of

grid points used in ocean and atmospheric models is large. In resolving the mesoscale activity of the ocean eddies and fronts and the atmospheric cyclones, the radius of deformation sets an upper limit on the model grid length. The maximum grid-length and the region-geometry then determine the number N_h of grid points in the horizontal over which the model is run. The number N_h is multiplied by the number N_v of gradations in the vertical. This again could be a large number depending on the precision needed in the thermodynamics of the surface layer. Usually, there is a finer vertical resolution near the surface than in the deeper ocean. For instance, with the radius of deformation of the order of 12 km, a mesoscale model of the Mediterranean Sea has $N_h = 441 \times 141$ grid-points in the horizontal, with N_v equal to 16. Thus, even a moderate size ocean geometry will involve fairly large data sets to be processed.

Many data formats exist, e.g., netCDF, HDF, GRIB, flat ascii files, binary, and packed binary. In some cases multiple time steps are stored in a single file and in other cases, each time step is stored in a separate file. The survey indicated many geographic regions of interest: global, ocean basins, North Atlantic, North Pacific, Gulf Stream, Mediterranean Sea, Gulf of Maine, Iceland Faeroes Front, Gulf of Mexico, Eastern Bore North Atlantic, Cathena region off of France, California Current, South China Sea, Labrador Current, Strait of Sicily, Great Lakes (Michigan and Erie), North America, Eastern Pacific region, and some very small domains such as the Central California coastal area.

The principal bathymetry/topography datasets being used are DBDB2, DBDB5, ETOPO5, and the Defense Mapping Agency (DMA) terrain data, although in many cases the standard datasets are smoothed when used in a model.

The list of scalar/vector/tensor output/derived fields (variables) of interest for visualization was as extensive as expected. It appears it will be useful to implement some calculator function so that the user can derive various diagnostic values within UASVS. Some of the fields mentioned were temperature, salinity, density, sea surface height, sound speed, dynamic height, geopotential height, dew point, mixing ratio, pressure, particle trajectories, 3D velocity, vorticity, potential vorticity, and their variations about a mean or monthly average (climatology).

5. CLIMATOLOGICAL DATA SETS

In order to provide the scientific community flexibility and interactivity in the use of the UASVS, access must be provided to the climatological datasets that are most often used in analysis, comparison, and verification of model results. The major ones mentioned in the survey were the Navy's Generalized Digital Environmental Model (GDEM), Levitus (1982), and Hellerman-Rosenstein (1983).

5.1 GDEM Climatology

GDEM provides seasonal (four) and annual climatologies of vertical profiles of temperature, salinity, and sound velocity from surface to bottom at standard depths, with a maximum of 30 levels. The last level is at the ocean bottom depth. If the ocean depth is greater than 5000 meters, a 31st level is added. GDEM provides coverage for the region 0-65N, with a spatial resolution of 30'. In addition to the more complete annual and seasonal data, climatologies are available monthly for surface temperatures.

5.2 Levitus Climatology

Levitus has compiled global, gridded datasets for annual, seasonal, and monthly climatologies of temperature and salinities. These climatologies are based on quality controlled hydrographic observations spanning the period of 1900-1978, and are presented as the Climatological Atlas of the World Ocean with a resolution of 1x1 degree in the horizontal and 33 standard depth levels from 0 m to 5500 m in the vertical.

5.3 Hellerman and Rosenstein Global Ocean Wind Stress Analysis

This climatology provides gridded analysis of surface winds based on data for the period 1870-1976 with 2x2 degree resolution.

6. CURRENT COMPUTING ENVIRONMENT

Most of the scientists polled have access to a variety of workstations, e.g., Sun, IBM RS/6000, SGI, and Stardents. Commonly used software includes the Application Visualization System (AVS), IBM Data Explorer (DX), Wavefront Data Visualizer, NCAR Graphics, University of Hawaii GMT package, University of Wisconsin VIS5D, NASA/NMC GEMPAK, UNIRAS, and SGI GL library. A few comments on the users' experience with these softwares follow.

- At the University of Southern Mississippi Center for Ocean and Atmosphere Modeling (COAM), they intend to combine PVWave and NCAR Graphics plotting programs in one package.
- The Harvard ocean modeling group is currently using the IBM DX system and is generally satisfied with it, except that it can not animate datasets with multiple frequencies.

- The NPS atmospheric modeling group is currently using VIS5D, GEMPAK, NCAR Graphics, and the Spray rendering package developed by the University of California at Santa Cruz (UCSC). The Spray program is a powerful tool but is not easy for a new user to learn. VIS5D does not allow on the fly computations for visualization. GEMPAK is versatile but has a crude user interface and does not produce publication quality graphics. VISUAL (an NCAR Graphics based display package) does basic contouring, satellite overlays, and observation plots using a much simpler user interface.
- At Rutgers the feasibility of using AVS is being explored. At present, its use is limited due to its lack of flexibility with unstructured grids (let alone spectral elements), input formats, etc. It also requires dedicated staff time to develop the network and data sets necessary for the visualization. For the 3D spectral-element model visualization, the Rutgers group currently uses NCAR Graphics and takes “k-slices” along the vertical where k is the vertical index. The slices are not horizontal except near the surface or if the topography is flat. The process is tedious and time-consuming. Some of the data remains inaccessible due to limited visualization capability. They plan to further explore AVS capabilities and/or write software that would interpolate SFEM model results onto a grid that could be handled by NCAR-graphics. They are enthusiastic about the development of the UASVS as it can provide a more flexible alternative than either AVS or NCAR-graphics.

7. RECOMMENDATIONS FOR VISUALIZATION FEATURES (RENDERING)

The main requirements from this survey are summarized below. The UASVS should be able to:

- Visualize 3D scalar/vector fields.
- Render isosurfaces.
- Visualize arbitrary slices of the 3D data, as well as horizontal, vertical, and isopycnal surfaces.
- Visualize data defined on spectral element grids with the minimum number of interpolation stages.
- Render contours.

- Produce 3-D vector plots and streamlines.
- Provide unified visualization of satellite images, observations, and model output overlays.
- Display the visualization on a sphere or a map projection of the users' choice.
- Implement calculator functions so that the user can derive various diagnostic values.
- Animate the data to see the time-evolution of the model output.
- Animate ocean and atmosphere at different rates.
- Store the record of cursor movement as the user follows a feature of interest, smooth the path, and automate the animation of a window around the moving path.
- Repeatedly start and stop the visual time-stepping at any time during the animation.
- Generate good quality VHS tape animations and publication quality hard copy plots.
- Work on a variety of workstations.
- Allow visualization to be distributed across clusters of workstations and/or scalable high performance computer systems.

8. CHALLENGES

The main challenges to the development of UASVS are due to widely different physical properties of the atmosphere and the ocean, and include:

- Fluid properties are drastically different in the ocean and in the air. Especially, there is a discontinuity in the density structure at the atmosphere/ocean boundary.
- Time and spatial scales are very different. Spatial scales are smaller in the ocean, being of the order of 10 km; while the atmosphere scales are larger being of the order of 1000 km. Processes tend to evolve slower in the ocean and faster in the atmosphere.

To address these issues, the capability of using separate, but coupled, grids for the ocean and the air will be provided. The grid positions and the associated variables on each grid will need to be animated at different rates.

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APPENDIX A: SURVEY QUESTIONS

1. Gridding structures predominantly being used, e.g., horizontal and vertical coordinate systems, grid sizes, grid resolution, etc., for the family of models, as well as climatological datasets, satellite data, observational datasets that are needed for visualization, analysis, comparison, and verification for model results.
2. Region of interest geometry, e.g., land/ocean masking information, bathymetry/-topography dataset being used.
3. List of scalar/vector/tensor output/derived fields (variables) of interest for visualization
 - Variable spatial distribution – Arakawa A grid or Arakawa C grid
 - Variable attributes – e.g., units, long name, valid minimum and maximum, missing value, etc.
 - Data Access – data format input/output, e.g., HDF, netCDF, flat file; physical data type (byte,int,float,...); organization of values (storage considerations); Rank (no. of values per element – scalar, vector, or tensor); time stamp tags, etc.
4. Recommendations for visualization features
5. Current computing environment for scientific visualization
 - Hardware/software
 - Strengths/weaknesses
 - Future Plans

APPENDIX B: LIST OF PRO BONO ADVISORS

Naval Research Laboratory:	Harley Hurlburt, Joe Metzger, Dan Fox
Naval Oceanographic Office:	Martha Head, Andy Johnson, Charlie Horton
Florida State University:	Jim O'Brien, Steve Meyers
Rutgers University:	Dale Haidvogel, Mohamed Iskandarani
Harvard University:	Hernan Arango, Carlos Lozano
Mississippi State University:	David Dietrich
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